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# In-Flight Performance with Night Vision Goggles During Reduced Illumination


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At the present time the U.S. Army is striving to attain around-the-clock operational capability for its tactical forces. The Night Vision Goggles have been developed to aid the Army pilot in attaining near-daytime capability at night. Previous research at the U.S. Army Aeromedical Research Laboratory has demonstrated the requirement for an investigation of the effects of low illuminance levels on aviator performance while wearing night vision goggles.

The current investigation examined man-helicopter system performance across several levels of reduced illumination. Neutral density filters were used to present six standard illumination conditions to aviators wearing night vision goggles, and to simulate unaided eye conditions to aviators wearing welder's goggles.

Significant differences in system performance were observed when aviators wore the night vision goggles. The results of the multivariate analysis of variance and recommendations based on observed performance are presented in this report.

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## SUMMARY

At the present time the U.S. Army is striving to attain around-the-clock operational capability for its tactical forces. The Night Vision Goggles have been developed to aid the Army pilot in attaining near-daytime capability at night. Previous research at the U.S. Army Aeromedical Research Laboratory has demonstrated the requirement for an investigation of the effects of low illuminance levels on aviator performance while wearing night vision goggles.

The current investigation examined man-helicopter system performance across several levels of reduced illumination. Neutral density filters were used to present six standard illumination conditions to aviators wearing night vision goggles, and to simulate unaided eye conditions to aviators wearing welder's goggles.

Significant differences in system performance were observed when aviators wore the night vision goggles. The results of the multivariate analysis of variance and recommendations based on observed performance are presented in this report.

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## INTRODUCTION

At the present time the US Army is striving to attain around-the-clock operational capability for its tactical forces. The objective is to achieve a near-daytime capability at night and during inclement weather. One device which has been developed as an aid in achieving this goal is the night vision goggles (AN/PVS-5).

The requirement for night viewing devices has been recognized for some time. As early as 1964, night vision goggles (NVG's) were under review by the Army Infantry for possible use by the individual soldier. More recently the potential applications of this device within the airborne environment have been recognized. Inasmuch as the flight environment presents many substantial differences from the originally designated ground application, questions have been raised regarding system effectiveness and the impact of NVG's on aviator performance in the tactical night environment[1,2].

Recognizing the major impact that the NVG's could have on Army aircraft systems, the U. S. Army Aeromedical Research Laboratory has developed an ongoing program to investigate performance characteristics of aviators while using the night vision goggles. To date, several research studies[3,4,5,6,7,8] have been completed and over 100 hours of flight experience have been obtained with the night vision goggles. Based on this experience, it became apparent that there was an immediate need to systematically investigate the role of illuminance as it affects the aviator's ability to fly with night vision goggles. The requirement for this research is based on the fact that below certain illuminance levels, night vision goggles produce a signal-to-noise (S/N) ratio that substantially degrades the pilot's ability to fly certain maneuvers.

These marginal illuminance levels impact Army Aviation in several ways. First they represent a major safety concern for the aviator because they limit his flying capability. Inadvertent entry into marginal light levels may provide the aviator with unusually hazardous flight conditions.

Second, the identification of illuminance levels necessary for adequate performance is necessary for both the tactical and the training environment. If a commander knows the light level at which he can expect full NVG's capability, he can then approximate the percentage of time they can be employed for any given reason, location, and time of night. Conversely, he can also determine the percentage of time they cannot be utilized.

The delineation of performance capabilities for various illuminance levels is hampered by the fact that the presence of marginal light levels cannot always be detected by wearing the NVG's on the ground. Thus, some other means is required to determine the presence of marginal or inadequate light levels. Ideally, such a means would not require additional equipment, such as photometers, but would consist of some non-hazardous flight maneuver which could be performed to determine if adequate light was available. This simple maneuver would then provide the necessary "go" or "no go" information.

Several operational characteristics of the NVG's at low illumination levels are particularly relevant to this investigation. These include the signal-to-noise ratio and the gain responses at very low light levels. At the present time, each intensifier tube in the night vision goggles has a particular signal-to-noise ratio and a gain characteristic. This provides the possibility that the responses of the two tubes in one set of goggles might be slightly different. The current specifications require the goggles to have a light gain of between 7,500 and 15,000. Experience has shown that there is a general deterioration in gain as tube life increases.

All intensifier tubes demonstrate a tendency to produce increased noise or sparkle at low illumination levels. It has been observed that under conditions of limited terrain definition and low light it is often difficult to determine if one is viewing an image or noise.

The present investigation was conducted to determine the effect of several low illumination conditions on aviator performance with NVG's, and under simulated unaided eye conditions.

## METHOD

### Subjects

Subjects for this investigation were six experienced Army rotary wing pilots. These aviators had an average of 2300 helicopter flight hours. Three of the pilots served as subjects in previous night vision goggles investigations and three others had recently been actively involved in the Phase I night training test (Night Hawk Operation) where extensive night flying with the unaided eye was conducted. The two safety pilots were USAARL research aviators highly experienced in the use of night vision goggles. Table 1 summarizes pilot experience as obtained from individual questionnaires.

### Equipment

This investigation utilized 40° field-of-view (FOV) night vision goggles (NVG's). Neutral density filters were used to control the illumination levels available to the goggles. Light-tight welder's goggles with neutral density filter lens were used to control the illumination available to the naked eye. Flight data were obtained

TABLE 1

SUMMARY OF PILOT EXPERIENCE QUESTIONNAIRE

| ITEM | SUBJECT NUMBER 1 | 2 | 3 | 4 | 5 | 6 | 7* | 8* |
|---|---|---|---|---|---|---|---|---|
| 1. Highest Rating in UH-1 Aircraft | IP | IP | SIP | SIP | IP | SIP | IP | SIP |
| 2. Total Rotary Wing Flight Hours | 2175 | 1600 | 2900 | 1900 | 1125 | 3590 | 1760 | 3700 |
| 3. Total Rotary Wing Night Flight Hours | 281 | 680 | 420 | 400 | 75 | 225 | 312 | 565 |
| 4. Total Number of Night Hours Flown Under Tactical Conditions | 15 | 400 | 300 | 200 | 200 | 160 | 80 | 300 |
| 5. Total Number of Night Hours Flown With No External Lights | 0 | 200 | 100 | 48 | 55 | 2 | 60 | 100 |
| 6. Total Hours Flown in the Last Three Months | 40 | 15 | 75 | 75 | 60 | 67 | 98 | 30 |
| 7. Total Night Hours Flown in the Last Three Months | 9 | 3 | 30 | 13 | 8 | 5 | 22 | 25 |
| 8. Number of Hours of Experience with Night Vision Goggles Before Investigation | 3 | 3 | 0 | 0 | 2 | 3 | 50 | 50 |

*Aviators labeled as subjects 7 and 8 served as safety pilots.

through the use of the Helicopter In-Flight Monitoring System (HIMS). Physical measures of illumination were made with a Spectra Pritchard Model 1980 Photometer.

## Night Vision Goggles (NVG's)

The night vision goggles (AN/PVS-5, Figure 1) are a head mounted binocular image intensification system. The NVG's are a unity magnification device with the image intensification being accomplished through the use of two 18mm wafer type micro channel image intensifier tubes (Figure 2 obtained from DTM 11-58855-238-24[9]). The goggles weigh 31 ounces, use a 2.7 volt mercury cell as a power source, and are attached to the aviator's SPH-4 flight helmet with two sets of straps fastened by stud snaps and velcro tabs. They incorporate a correction range of eight diopters and can be manually focused from ten inches to infinity. The best visual acuity obtainable through the 40° FOV NVG's is 20/60 in Snellen notation.

The night vision goggles utilized in this investigation possessed two matched image intensifier tubes, each with a signal-to-noise ratio of 5:5. A green phosphor (Type 10-52) in the intensification tubes, results in the entire 40° FOV being presented in shades of green.

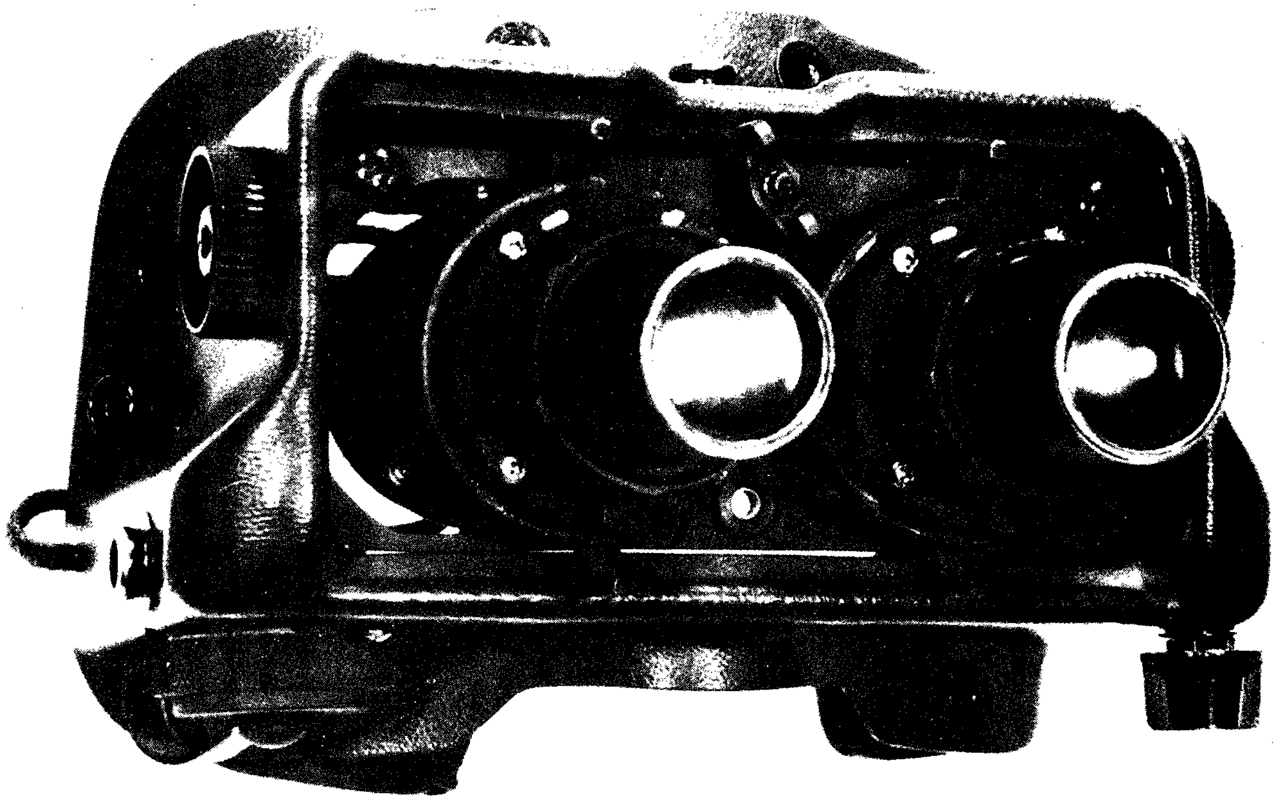


FIGURE 1. NIGHT VISION GOGGLES.

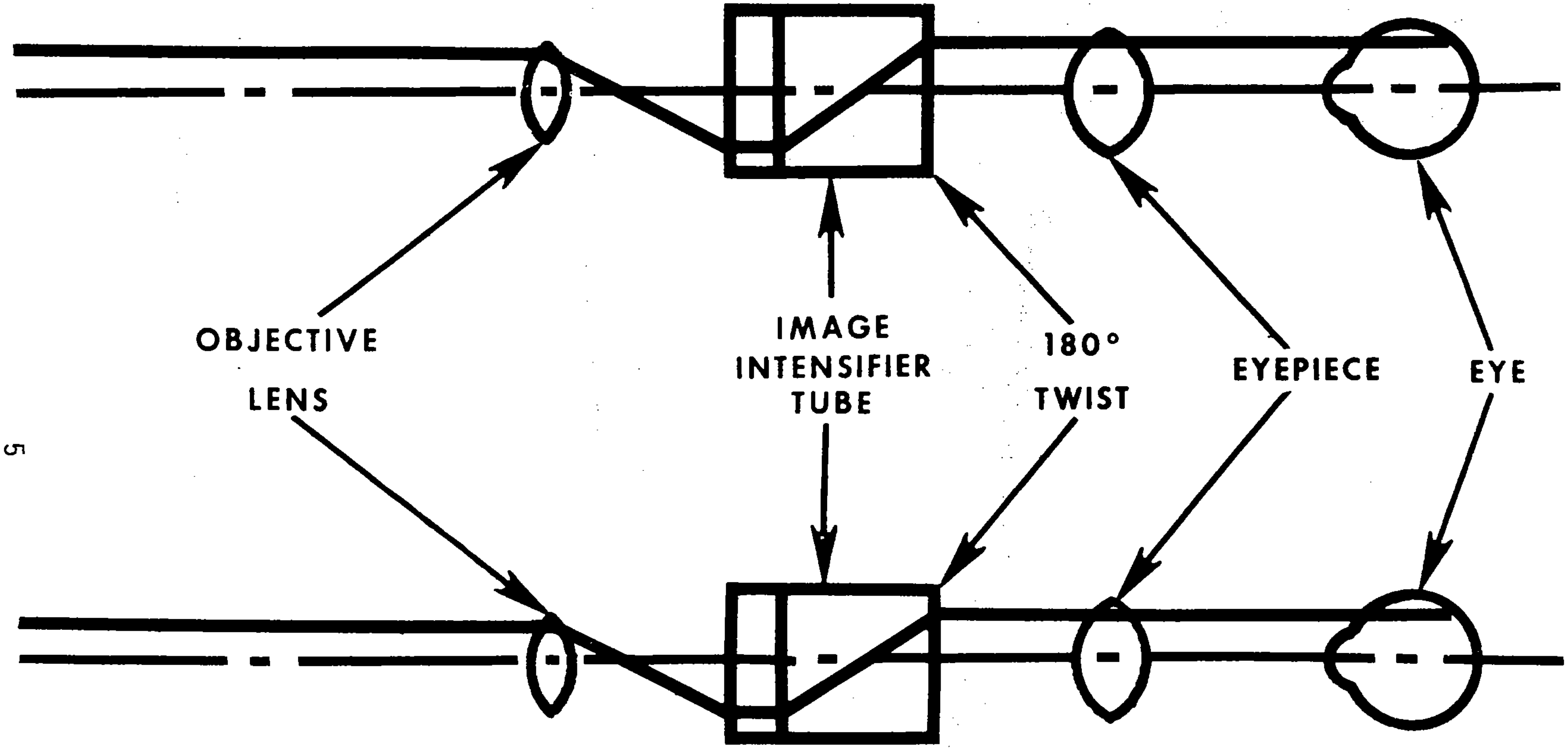



FIGURE 2. OPTICAL SCHEMATIC OF NVG.

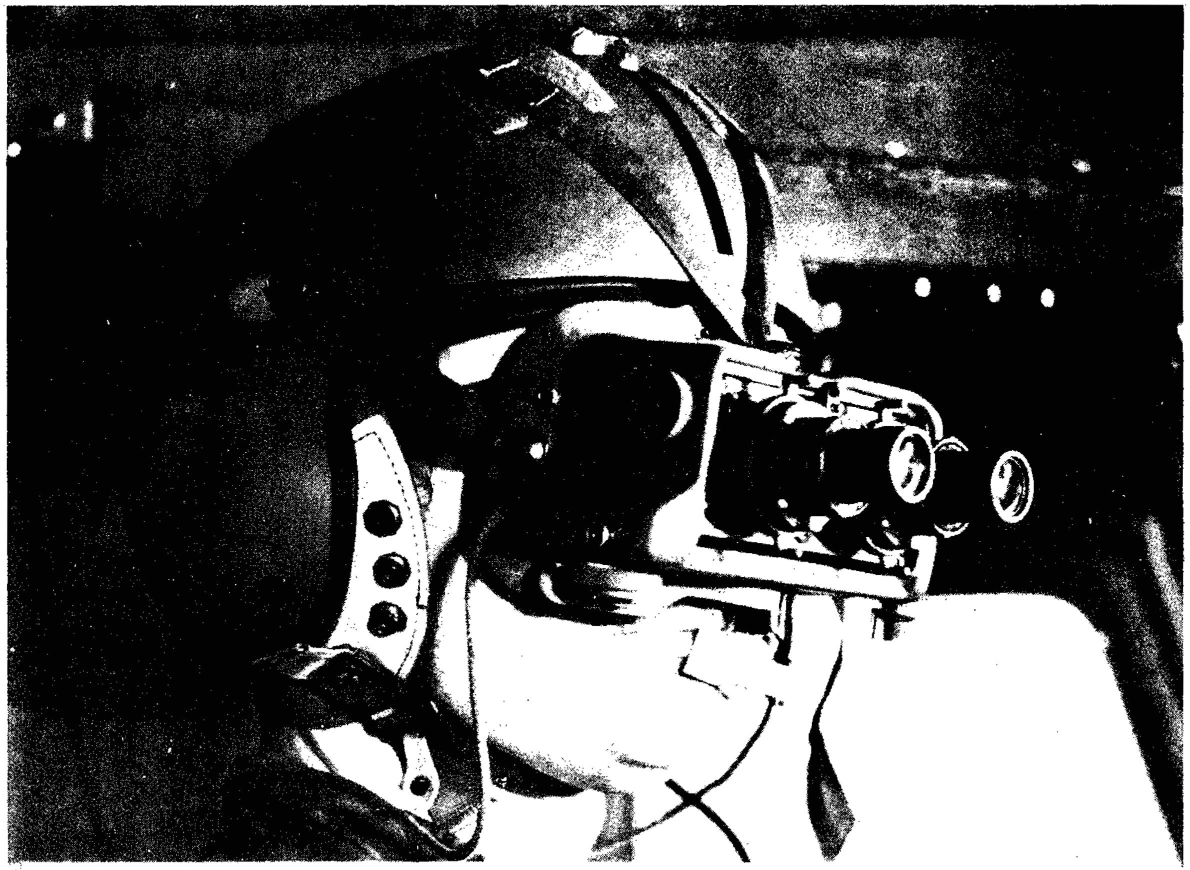


FIGURE 3. AVIATOR WEARING NIGHT VISION GOGGLES.

The illuminance level available to the night vision goggles was controlled by placing tube caps over the end of the NVG's objective lens. These tube caps contained the appropriate number of Kodak Wratten No. 96 Neutral Density Filters.

### Naked Eye Simulators (NES)

A set of light-tight welder's goggles (Figure 4) were used to control the illuminance levels available to the unaided eye. For this investigation, the normal smoked lens were replaced by the appropriate number of Kodak Wratten No. 96 Neutral Density Filters. Illuminance levels were monitored throughout the investigation, and these frequent measures were used to establish the correct neutral density setting for flights with both the naked eye simulators and the night vision goggles.

### Aircraft

Subjects in this investigation flew an Army JUH-1H helicopter modified to provide input to the HIMS. For all trials, the aircraft was flown without external lights or internal cockpit lights. The investigation team was isolated by a blackout curtain in the rear of the aircraft.

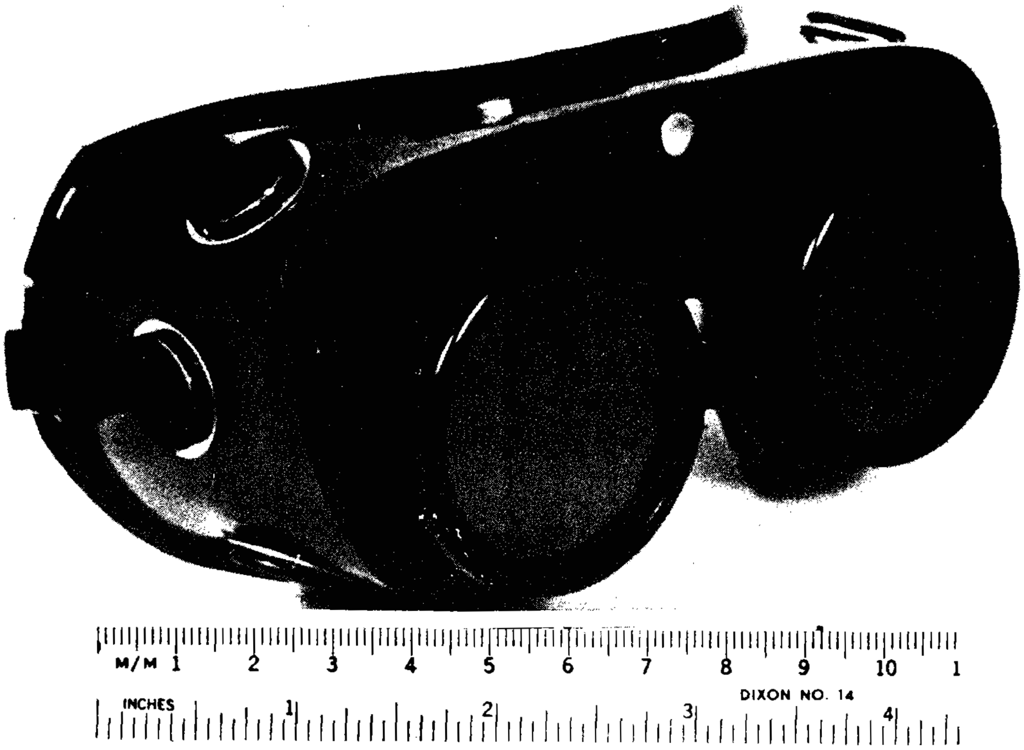
### Helicopter In-Flight Monitoring System (HIMS)

The HIMS, (Figure 5) provides real time acquisition of all major motion and control parameters. The HIMS monitors and records aircraft movements in six degrees of freedom as well as all pilot control movements on the cyclic, collective, pedals, and throttle. Measures of rates and accelerations along each axis are also obtained. An on-board radio ranging system is utilized to continuously track the research aircraft's position within USAARL's 100 square mile test range. The HIMS continuously records 20 channels of information using an on-board incremental tape recorder.

Complete processing of the HIMS output tape provides 325 direct or derived measures of aircraft and pilot performance. A more complete description of this system is available in USAARL Report No. 72-11[10].

## PROCEDURE

Prior to the actual testing, several flight maneuvers were examined for applicability in terms of safety and control difficulty. After empirical investigation, it was determined that holding a stationary, three-foot hover over a dark asphalt runway, while facing a minimally textured grassy area, was a discriminating maneuver which became more difficult as the illumination level was reduced. This three-foot hover was selected as the primary test maneuver.




WELDER'S GOGGLES
NAKED EYE SIMULATORS

**FIGURE 4. NAKED EYE SIMULATORS.**

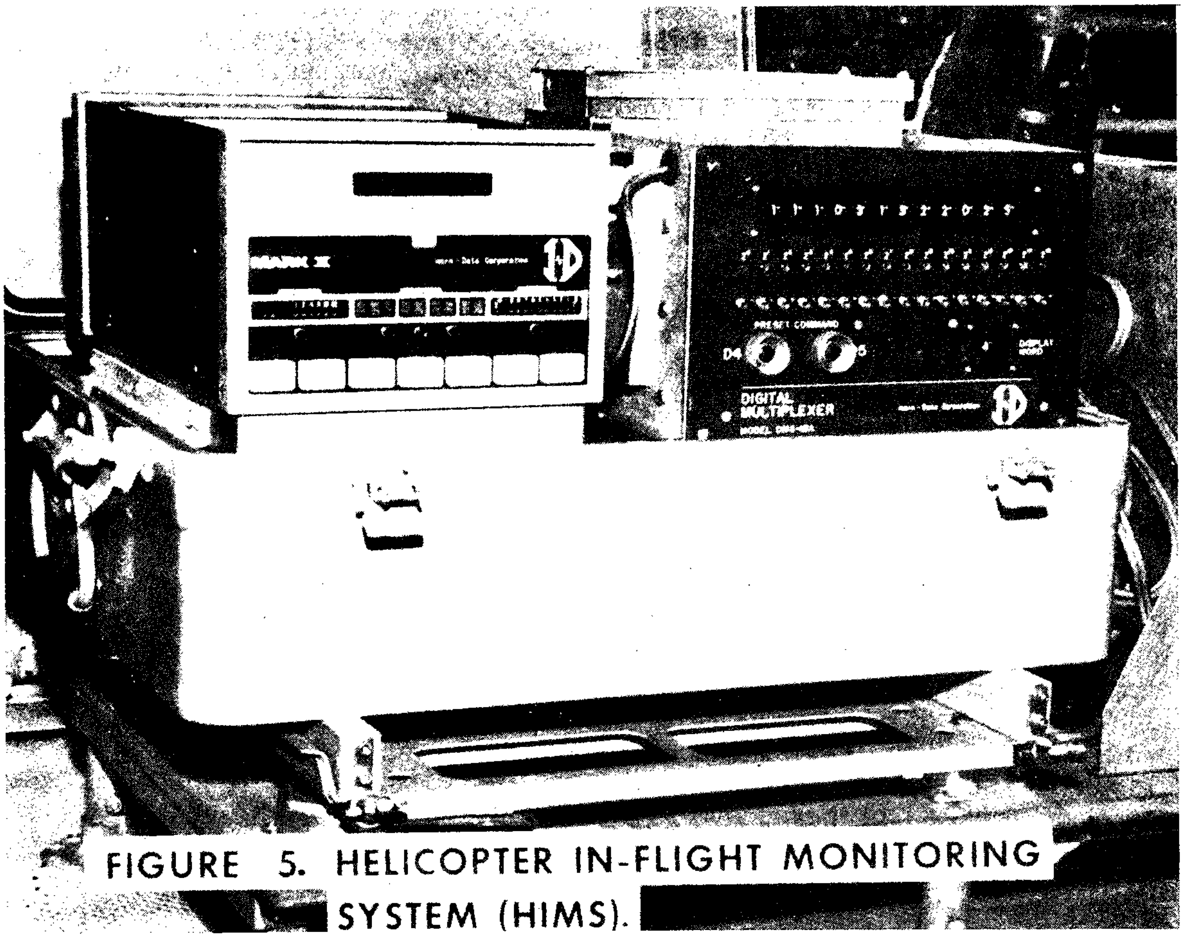



FIGURE 5. HELICOPTER IN-FLIGHT MONITORING SYSTEM (HIMS).

Subject Examination and Familiarization

Six experienced aviators selected as subjects visited the laboratory immediately prior to the start of field testing. At that time, they received a complete briefing concerning the objectives and procedures that would be used during the investigation and were examined for static visual acuity and refractive error. During the briefing, the subjects' flight helmets were modified for mounting the night vision goggles.

Prior to the night testing, subjects received a day's familiarization flight which entailed a flight to the test area, 30 minutes of practice with the night vision goggles, and 30 minutes of practice with the naked eye simulators. During the practice sessions, the subjects were required to perform a minimum of five 30-second stationary hovers with each device. The remaining time was allocated for practice on any maneuver desired, generally hover taxi work and stationary hovers.

In-Flight Investigation

Subjects were tested during three nights over a five-day period. Each night two subjects were flown to the USAARL research facility at High Falls Stagefield. The first pilot to be tested wore red dark adaptation glasses on the flight out to the test site and received approximately 25 minutes of dark adaptation. The second pilot tested also received 25 minutes dark adaptation prior to his test flight.

Upon arrival at High Falls, one pilot was taken to the test area on the asphalt runway and given a viewing device, either night vision goggles (NVG's) or naked eye simulators (NES) containing an appropriate set of neutral density filters. The subject then performed a series of 24 thirty-second stationary hovers under controlled illuminance levels, after which he performed another series of 24 thirty-second hovers with the remaining viewing device. At the conclusion of the second series, the subject removed the viewing device and performed two thirty-second hovers using the unaided eye.

Six standard discrete illumination level conditions were encountered by each subject during the series of 24 hovers for each viewing device. Each of the six levels were presented twice with the pilot performing two successive hovers at each presentation. The six illumination levels were initially presented to the subjects in either an ascending (darker to lighter) or descending (lighter to darker) manner. After the first six stages (i.e., six steps of ascending illumination levels) the manner of presentation was reversed (i.e., six steps of descending illumination levels). Thus, each subject performed four maneuvers (two pairs) at each illumination level. The presentation of viewing devices (NVG vs NES) and the initial presentation of illumination levels (ascending vs descending) were counterbalanced between subjects. A summary of the order of presentation of viewing devices and illumination level conditions for each subject is found in Table 2. The illumination levels presented for flights with the night vision goggles and the naked eye simulators are found in Table 3A. Values are presented in USAARL factor levels, which will be discussed later.

TABLE 2

LAYOUT OF EXPERIMENTAL CONDITIONS

| Night | % of Moon Illuminated | Subject # | 1st Hover Viewing Device[1] | Series Light Level Seq[2] | 2d Hover Viewing Device[1] | Series Light Level Seq[2] |
|---|---|---|---|---|---|---|
| 1 | 70% | 8 | NES | D-A | NVG's | A-D |
| | | 7 | NVG's | D-A | NES | A-D |
| 2 | 80% | 1 | NVG's | D-A | NES | A-D |
| | | 2 | NES | D-A | NVG's | A-D |
| 3 | 89% | 3 | NVG's | D-A | NES | D-A |
| | | 5 | NVG's | A-D | NES | D-A |
| 4 | 98% | 4 | NES | A-D | NVG's | A-D |
| | | 6 | NES | A-D | NVG's | D-A |

[1]NVG's = Night Vision Goggles - NES = Naked Eye Simulators (Welder's Goggles)

[2]D = Descending Light Levels (Lighter to Darker).
A = Ascending Light Levels (Darker to Lighter).

Before each maneuver, the aircraft was placed in a standard position by the safety pilot to insure that the subject had no distinct visual cues to his immediate front. The subject then took control of the aircraft, established what he considered to be a three-foot hover, and then attempted to maintain a stabilized hover for a thirty-second period. At the end of the thirty seconds, the safety pilot assumed control and repositioned the aircraft on the runway. A standard policy regarding termination of the maneuver was established prior to testing. This policy required the safety pilot to assume control of the aircraft only when there was an immediate possibility that the aircraft would be damaged. Thus, several of the subjects were allowed to perform skid touchdowns during the testing period as long as the rate of movement was not severe enough to incur aircraft damage. If the safety pilot was forced to assume control for all maneuvers at two successive illumination levels, testing at that illuminance level was terminated. However, it was never necessary to implement this procedure.

### Measurement

Subject performance during the investigation was monitored and recorded by the HIMS. Due to a partial equipment malfunction, measures available for this investigation were those of aircraft pitch, roll, and heading and aircraft location on the X and Y axis of the test area's coordinate system.

Throughout the testing period, ambient illumination levels were monitored via the photometer and changes in light level were transmitted to the investigators on board the aircraft.

### USAARL Illumination Factor Level

The USAARL Light Level Factors were used in this investigation to provide a convenient and uniform method of converting existing illumination levels into a more meaningful scale. The USAARL Light Level Factor Scale has a range of 1 to 100. On this scale, 1 represents a clear, star light night with no moon, and 100 represents a clear, full moon night. The calculation of the USAARL Factor is conducted in the following manner:

$$\text{USAARL Illumination Factor} = \frac{\text{Light Level in Ft. Candles} \times \text{Transmissibility}}{2.0 \times 10^{-4}}$$

Transmissibility = 1/antilog of the Neutral Density Filter.

Examples of USAARL Illumination Factors are found in Table 3B.

## ANALYSES AND RESULTS

Data analyses utilized for this investigation consisted of (1) the pre-analysis processing of the raw data obtained from the HIMS; (2) the selection of variables for analysis; and (3) the analysis and testing of appropriate in-flight variables.

### Pre-Analysis Processing

Three separate computer programs are necessary to convert data obtained from the HIMS into standard units of measure. This conversion places

TABLE 3

EXPERIMENTAL LIGHT LEVEL CONDITIONS

A.

| | NIGHT VISION GOGGLES | | NAKED EYE SIMULATORS | |
|---|---|---|---|---|
| | Proposed Standard | Obtained Values | Proposed Standard | Obtained Values |
| 1 | 1.0 | 1.0 | 3.0 | 4.0-3.0 |
| 2 | 1.3 | 1.26-1.3 | 5.0 | 5.0 |
| 3 | 1.6 | 1.59-1.6 | 6.0 | 6.0 |
| 4 | 2.0 | 2.0 | 8.0 | 8.0 |
| 5 | 3.0 | 3.0 | 10.0 | 10.0-12.0 |
| 6 | 5.0 | 5.0 | 16.0 | 16.0-18.0 |

All values in table above are USAARL light level factors.

B.

USAARL ILLUMINATION FACTOR LEVELS

| Illumination Ft. Candles | USAARL Factor | Moon Condition |
|---|---|---|
| $2.0 \times 10^{-4}$ | 1 | No moon - clear star light |
| $5.0 \times 10^{-3}$ | 25 | 1/4 moon |
| $1.0 \times 10^{-2}$ | 50 | 1/2 moon |
| $1.5 \times 10^{-2}$ | 75 | 3/4 moon |
| $2.0 \times 10^{-2}$ | 100 | Full moon |

the original voltage measures into meaningful values such as degrees of heading and inches of travel for aircraft controls. These engineering units are developed for each data sample obtained during the course of the maneuver. All sample values for each maneuver are then averaged over the time span of that specific maneuver and these mean values are utilized as the dependent measures in statistical analysis.

## Variable Selection

At the initiation of the analysis phase, thirty variables were considered as appropriate for use in the selection of a final variable set. These variables are presented in Table 4.

TABLE 4

PERFORMANCE MEASURES DERIVED FROM HIMS

| | | |
|---|---|---|
| 1. | Pitch | - Mean |
| 2. | | - Standard Deviation |
| 3. | | - Average Absolute Error |
| 4. | | - Root Mean Square Error |
| 5. | | - Maximum Value |
| 6. | | - Minimum Value |
| 7. | Roll | - Mean |
| 8. | | - Standard Deviation |
| 9. | | - Average Absolute Error |
| 10. | | - Root Mean Square Error |
| 11. | | - Maximum Value |
| 12. | | - Minimum Value |
| 13. | Heading | - Mean |
| 14. | | - Standard Deviation |
| 15. | | - Average Absolute Error |
| 16. | | - Root Mean Square Error |
| 17. | | - Maximum Value |
| 18. | | - Minimum Value |
| 19. | X Position | - Mean |
| 20. | | - Standard Deviation |
| 21. | | - Average Absolute Error |
| 22. | | - Root Mean Square Error |
| 23. | | - Maximum Value |
| 24. | | - Minimum Value |
| 25. | Y Position | - Mean |
| 26. | | - Standard Deviation |
| 27. | | - Average Absolute Error |
| 28. | | - Root Mean Square Error |
| 29. | | - Maximum |
| 30. | | - Minimum |

The first step in the variable selection process was to determine the degree of redundancy or overlap between the variables. For this purpose, a 30 by 30 correlation matrix was developed which contained all pair-wise comparisons for these variables. This information was then submitted to a simple cluster analysis. All variables that were highly correlated were identified and grouped within a particular cluster. The development of the correlation matrix and subsequent cluster analysis were conducted separately for night vision goggles maneuvers and for the naked eye simulators maneuvers. The results of the cluster analysis for the NES maneuvers and for the NVG's maneuvers are found in Table 5A, B, and Table 6A, B, respectively.

The second phase in the selection of variables consisted of determining the degree to which each variable showed a relationship or trend to changes in illumination level. Measures for each variable at each illumination level were tested for trend, using orthogonal polynomial comparisons. Linear, quadratic, cubic, and a combination of higher order trends were examined for each variable. Those variables that demonstrated a significant trend, that is a change in the variable value corresponding to a change in illumination level for NES maneuvers, are presented in Table 7.

TABLE 5

NAKED EYE SIMULATOR MANEUVERS
CLUSTER ANALYSIS

**A. Clustered Variables** — Correlations

Cluster 1

| Variable | | 1 | 2 |
|---|---|---|---|
| 1) Y Position - Average Absolute Error | 1 | 1.00 | |
| 2) Y Position - Root Mean Square Error | 2 | .99 | 1.00 |

Cluster 2

| Variable | | 3 | 4 |
|---|---|---|---|
| 3) X Position - Average Absolute Error | 3 | 1.00 | |
| 4) X Position - Root Mean Square Error | 4 | .99 | 1.00 |

Cluster 3

| Variable | | 5 | 6 | 7 |
|---|---|---|---|---|
| 5) Roll - Standard Deviation | 5 | 1.00 | | |
| 6) Roll - Average Absolute Error | 6 | .90 | 1.00 | |
| 7) Roll - Root Mean Square Error | 7 | .93 | .99 | 1.00 |

Cluster 4

| Variable | | 8 | 9 |
|---|---|---|---|
| 8) Heading - Average Absolute Error | 8 | 1.00 | |
| 9) Heading - Root Mean Square Error | 9 | .98 | 1.00 |

Cluster 5

| Variable | | 10 | 11 |
|---|---|---|---|
| 10) Pitch - Average Absolute Error | 10 | 1.00 | |
| 11) Pitch - Root Mean Square Error | 11 | .95 | 1.00 |

Cluster 6

| Variable | | 12 | 13 | 14 |
|---|---|---|---|---|
| 12) Y Position - Mean | 12 | 1.00 | | |
| 13) Y Position - Maximum Value | 13 | .94 | 1.00 | |
| 14) Y Position - Minimum Value | 14 | .95 | .82 | 1.00 |

**B. Unclustered Variables**

15) Pitch - Mean
16) Pitch - Standard Deviation
17) Pitch - Maximum Value
18) Pitch - Minimum Value
19) Roll - Mean
20) Roll - Maximum Value
21) Roll - Minimum Value
22) Heading - Mean
23) Heading - Standard Deviation
24) Heading - Maximum Value
25) Heading - Minimum Value
26) X Position - Mean
27) X Position - Standard Deviation
28) Y Position - Standard Deviation
29) X Position - Maximum Value
30) X Position - Minimum Value

TABLE 6

NIGHT VISION GOGGLES MANEUVERS
CLUSTER ANALYSIS

A. Clustered Variables — Correlations

Cluster 1

1) X Position - Average Absolute Error
2) X Position - Root Mean Square Error

| | 1 | 2 |
|---|---|---|
| 1 | 1.00 | |
| 2 | .99 | 1.00 |

Cluster 2

3) Roll - Average Absolute Error
4) Roll - Root Mean Square Error
5) Roll - Standard Deviation

| | 3 | 4 | 5 |
|---|---|---|---|
| 3 | 1.00 | | |
| 4 | .99 | 1.00 | |
| 5 | .90 | .92 | 1.00 |

Cluster 3

6) Heading - Average Absolute Error
7) Heading - Root Mean Square Error

| | 6 | 7 |
|---|---|---|
| 6 | 1.00 | |
| 7 | .99 | 1.00 |

Cluster 4

8) Y Position - Average Absolute Error
9) Y Position - Root Mean Square Error

| | 8 | 9 |
|---|---|---|
| 8 | 1.00 | |
| 9 | .99 | 1.00 |

Cluster 5

10) Pitch - Average Absolute Error
11) Pitch - Root Mean Square Error

| | 10 | 11 |
|---|---|---|
| 10 | 1.00 | |
| 11 | .98 | 1.00 |

B. Unclustered Variables

12) Pitch - Mean
13) Pitch - Standard Deviation
14) Pitch - Maximum Value
15) Pitch - Minimum Value
16) Roll - Mean
17) Roll - Maximum Value
18) Roll - Minimum Value
19) Heading - Mean
20) Heading - Standard Deviation
21) Heading - Maximum Value
22) Heading - Minimum Value
23) X Position - Mean
24) X Position - Standard Deviation
25) Y Position - Mean
26) Y Position - Standard Deviation
27) X Position - Maximum Value
28) X Position - Minimum Value
29) Y Position - Maximum Value
30) Y Position - Minimum Value

TABLE 7

VARIABLES DEMONSTRATING SIGNIFICANT TRENDS OVER ILLUMINATION LEVELS USED DURING NES MANUEVERS

| Variables | Order of the Trend |
|---|---|
| 1) Pitch - Standard Deviation | Linear |
| 2) Pitch - Minimum Value | Linear |
| 3) Roll - Standard Deviation | Linear |
| 4) Roll - Average Absolute Value | Linear |
| 5) Roll - Root Mean Square (RMS) Error | Linear |
| 6) Roll - Maximum Value | Linear |
| 7) Roll - Minimum Value | Linear |
| 8) Heading - Mean | Linear |
| 9) Heading - Standard Deviation | Linear |
| 10) Heading - Average Absolute Error | Linear |
| 11) Heading - RMS Error | Linear |
| 12) Heading - Minimum Value | Linear |
| 13) X Position - RMS Error | Linear (.073) |
| 14) Y Position - Maximum Value | Linear (.059) |
| 15) Y Position - Mean | Linear (.095) |

*Each of the first twelve variables produced a linear trend that was significant at the .05 level or less. P levels for remaining variables are indicated in parenthesis.

At this point, the individual clusters were examined and those variables which were highly correlated with the representative (i.e., most highly correlated) variable from each cluster were eliminated. The eleven remaining NES variables are presented in Table 8A. This final set was further reduced by selecting out one variable for each major axis measured, to be used in the final analysis stage. This list of five variables is presented in Table 8B.

TABLE 8

NES VARIABLES SELECTED FOR FURTHER ANALYSIS

A. Uncorrelated Variables

1) Pitch - Standard Deviation
2) Pitch - Minimum Value
3) Roll - RMS Error
4) Roll - Maximum Value
5) Roll - Minimum Value
6) Heading - Mean
7) Heading - Standard Deviation
8) Heading - RMS Error
9) Heading - Minimum Value
10) X Position - RMS Error
11) Y Position - Mean

B. Major Axis Variables

1) Pitch - Standard Deviation
2) Roll - RMS Error
3) Heading - RMS Error
4) X Position - RMS Error
5) Y Position - Mean

The variables that showed a significant trend relationship with illumination levels during NVG's maneuvers are presented in Table 9.

TABLE 9

VARIABLES DEMONSTRATING SIGNIFICANT TRENDS OVER ILLUMINATION LEVELS USED DURING NVG's MANEUVERS

| Variables* | Order of the Trend |
|---|---|
| 1) Pitch - Standard Deviation | Quadratic |
| 2) Pitch - Minimum Value | Quadratic |
| 3) Roll - Mean | Linear, Cubic |
| 4) Roll - Standard Deviation | Linear |
| 5) Roll - Average Absolute Error (AAE) | Linear |
| 6) Roll - Root Mean Square (RMS) Error | Linear |
| 7) Roll - Maximum Value | Linear, Cubic |
| 8) Heading - Standard Deviation | Linear, $\geq$ 4th |
| 9) Heading - AAE | Linear, $\geq$ 4th |
| 10) Heading - RMS Error | Linear, $\geq$ 4th |
| 11) Heading - Minimum Value | Cubic, $\geq$ 4th |
| 12) X Position - RMS Error | Linear (.065) |
| 13) X Position - Standard Deviation | Linear |
| 14) Y Position - Standard Deviation | Linear (.056) |

*Unless indicated in parenthesis, p levels are .05 or below.

Table 10A and B represents the variable sets used in the final analysis of the night vision goggles maneuvers.

TABLE 10

NVG's VARIABLES SELECTED FOR FURTHER ANALYSIS

A. Uncorrelated Variables

1) Pitch - Standard Deviation
2) Pitch - Minimum Value
3) Roll - Mean
4) Roll - Root Mean Square (RMS) Error
5) Roll - Minimum Value
6) Heading - Standard Deviation
7) Heading - RMS Error
8) Heading - Minimum Value
9) X Position - RMS Value
10) X Position - Standard Deviation
11) Y Position - Standard Deviation

B. Major Axis Variables

1) Pitch - Standard Deviation
2) Roll - RMS Error
3) Heading - RMS Error
4) X Position - Standard Deviation
5) Y Position - Standard Deviation

## Covariates

During the analysis phase, items of information obtained from the pilot questionnaire were developed as covariates and tested to determine if these data were useful in predicting aviator performance. Table 11 presents a list of the covariates considered during analysis of both NES and NVG's maneuvers.

TABLE 11

MEASURES OF PILOT EXPERIENCE USED AS COVARIATES

1) Sequence number of each maneuver over the entire test flight.
2) Results of the night vision test.
3) Total rotary wing flight hours.
4) Total rotary wing flight hours at night.
5) Total flight hours for the last three months.
6) Total night flight hours for the last three months.
7) Total tactical flight hours at night.
8) Total night hours flown with no external light.
9) Total number of previous hours experience with the night vision goggles.

## Analyses of In-Flight Variables

After the variable selection process was completed, two types of analyses were conducted. First, the reduced variable sets were analyzed using a multivariate orthogonal polynomial test for trend. During this phase, each covariate was examined to determine if it provided a significant reduction in the observed variance.

The second phase tested for differences in aircraft performance across levels of illumination for both NVG's and NES maneuvers. In this phase a test for individual subject differences was included.

## Multivariate Test for Trend

This phase of the analysis utilized the multivariate technique of orthogonal polynomial contrasts to determine if significant trends in aircraft performance were present across different levels of illumination. This procedure served to indicate what type of trend was significant when the entire set of appropriate variables was examined and determined the adequacy of covariates in reducing the sample variance. Several analyses were conducted to determine the optimal set of covariates. These analyses were conducted on both the set of eleven variables selected as demonstrating individual trends over light levels, and the set of five variables which included measures on each of the five major axes (Tables 8 and 10).

Analyses for both the NES and NVG's data indicated that the first six covariates provided the optimal set for the trend analyses of both the eleven variable trend tests and the five variable trend tests. Indeed, it was found that three covariates, i.e., tactical night hours, no light night hours, and NVG's hours, were redundant with a linear combination of the other six covariates. The summary table obtained from the multivariate orthogonal polynomial trend tests for the NES data is found in Table 12.

TABLE 12

MULTIVARIATE ORTHOGONAL POLYNOMIAL TEST FOR TREND IN NES MANEUVERS

| Source | F-Ratio* | Hypothesis df | Error df | P Less Than | Canonical R |
|---|---|---|---|---|---|
| A. Trend Test on 11 Variables and 6 Covariates | | | | | |
| Within Cells Regression | 6.185 | 66 | 658 | .001 | .818 |
| Quartic and Higher Order | .982 | 22 | 244 | .488 | .317 |
| Cubic | .747 | 11 | 122 | .692 | .251 |
| Quadratic | 1.233 | 11 | 122 | .273 | .316 |
| Linear | 3.013 | 11 | 122 | .001 | .462 |
| B. Trend Test on 5 Variables and 6 Covariates | | | | | |
| Within Cells Regression | 6.030 | 30 | 514 | .001 | .663 |
| Quartic and Higher Order | .614 | 10 | 256 | .802 | .160 |
| Cubic | 1.037 | 5 | 128 | .399 | .197 |
| Quadratic | .995 | 5 | 128 | .424 | .193 |
| Linear | 5.626 | 5 | 128 | .001 | .424 |

*Tests of significance uses Wilks-Lambda criterion. Within Cells Regression and Quartic trend tests present only the first root.

Data presented in Table 12 indicate that aircraft performance, as represented by these variable sets, shows a linear trend over illumination levels. Similar summary tables for the NVG's are in Table 13.

TABLE 13

MULTIVARIATE ORTHOGONAL POLYNOMIAL TEST FOR TREND IN NVG's DATA

| Source | F-Ratio* | Hypothesis df | Error df | P Less Than | Canonical R |
|---|---|---|---|---|---|
| A. Trend Test on 11 Variables and 6 Covariates | | | | | |
| Within Cells Regression | 7.704 | 66 | 642 | .001 | .865 |
| Quartic and Higher Order | .824 | 22 | 238 | .694 | .291 |
| Cubic | .944 | 11 | 119 | .501 | .283 |
| Quadratic | 1.572 | 11 | 119 | .116 | .356 |
| Linear | 3.488 | 11 | 119 | .001 | .494 |
| B. Trend Test on 5 Variables and 6 Covariates | | | | | |
| Within Cells Regression | 8.752 | 30 | 502 | .001 | .715 |
| Quartic and Higher Order | .915 | 10 | 250 | .520 | .216 |
| Cubic | .835 | 5 | 125 | .527 | .180 |
| Quadratic | 1.262 | 5 | 125 | .285 | .219 |
| Linear | 5.124 | 5 | 125 | .001 | .412 |

*Tests of significance uses Wilks-Lambda criterion. Within Cells Regression and Quartic trend tests present only the first root.

It is interesting to note that in both the eleven variable set and the five variable set, all higher order trends observed in the analysis of individual variables (Table 9) were no longer present. Again, a linear trend of aircraft performance over illumination levels is demonstrated.

Multivariate Test for Differences Across Illumination Levels

The second analysis phase examined selected measures of aircraft performance to determine if significant differences existed between illumination levels. A multivariate two-way analysis of variance examining an illumination level factor and a subject factor was utilized for this phase of the analysis. The illumination level factor contained six levels corresponding to the six illumination levels used for NVG's maneuvers and for the six standard levels used for the NES maneuvers. During analysis of the NES maneuvers, it was necessary to collapse or shift 18 of the 144 maneuvers, or 12.5% of the data, into the appropriate standard light level categories to insure a full factorial design.

The subject factor in the multivariate two way analysis of variance was used to accommodate the repeated measures structure of the data acquisition process.

Stability of the multivariate analysis requires that the number of variables be less than or equal to the number of subjects. Thus, this phase of the analysis considered only those variables representing measures on the five major axes.

With the inclusion of a subject factor in this phase of the analysis, it was discovered that the contribution of the covariates representing the individual pilot's experience was markedly reduced. In fact, it was determined that for the NES data only two covariates, sequence number of maneuver, and night vision test results contributed to the reduction of observed variance. However, this contribution was not significant and was eliminated from the analysis. For the NVG's data, it was determined that only three covariates, maneuver number, night vision test, and total rotary wing hours contributed to variance reduction. Again, this contribution was not significant and these covariates were eliminated from further consideration.

The results of the multivariate two-way analysis of variance are presented in Table 14. It indicates that for both the NES maneuvers and the NVG's maneuvers there was a significant difference between subjects. For the NES maneuvers there were no significant differences between the illumination levels utilized. However, there were significant differences in aircraft performance across illumination levels used for the night vision goggles maneuvers. To determine where these differences existed, pair-wise tests were conducted between each of the illumination levels. The probability levels associated with each of these tests are presented in Table 15. Again, this was a multivariate analysis which considered all five of the major axis variables simultaneously.

TABLE 14

TWO-WAY MULTIVARIATE ANALYSIS OF VARIANCE

| Source | F-Ratio* | Hypothesis df | Error df | P Less Than | Canonical R |
|---|---|---|---|---|---|
| A. Analysis of NES Data--5 Criteria, 0 Covariates | | | | | |
| Light Levels | 1.318 | 25 | 79 | .178 | .745 |
| Subjects | 4.757 | 25 | 79 | .001 | .862 |
| B. Analysis of NVG Data--5 Criteria, 0 Covariates | | | | | |
| Light Levels | 1.796 | 25 | 79 | .026 | .796 |
| Subjects | 8.452 | 25 | 79 | .001 | .934 |

*Significance test uses Wilks-Lambda criterion. Only the first root is presented.

TABLE 15

PROBABILITY LEVELS* FOR PAIR-WISE COMPARISONS BETWEEN ILLUMINATION LEVELS FOR NVG's MANEUVERS

| USAARL FACTOR VALUE | | 1.0 | 1.3 | 1.6 | 2.0 | 3.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| | LEVELS | 1 | 2 | 3 | 4 | 5 | 6 |
| 1. | 1 | | .029 | .114 | .261 | .236 | .006 |
| 1.3 | 2 | | | .634 | .492 | .001 | .001 |
| 1.6 | 3 | | | | .014 | .001 | .095 |
| 2.0 | 4 | | | | | .091 | .001 |
| 3.0 | 5 | | | | | | .694 |
| 5.0 | 6 | | | | | | |

*Probability levels associated with single degree of freedom F-ratios.

The mean scores for the five major axis variables at each NVG's illumination level are found in Table 16. This table also includes the standardized discriminant function coefficient for each variable, which indicates the relative contribution of these variables to the observed significant differences. The data demonstrates that there was a significant improvement in performance; that is to say, a reduction in error scores between the 1.0 USAARL factor level and the 1.3 factor. Performance at the 1.3 and 1.6 USAARL factor levels is similar, but increasing the illumination levels to 2.0 and again to the 3.0 factor promotes significant improvement in performance. It would appear that the increase from 3.0 to 5.0 USAARL factor does not markedly improve the aircraft system performance. There is a significant improvement in performance (i.e., reduction in error) between the two lowest USAARL factor levels (1.0 to 1.3 USAARL factor), but it takes a change of approximately .7 USAARL factor to add any additional improvement in performance. This improvement, with increases in illuminance continues until the 3.0 USAARL factor is reached, at which time increases in illumination provide no significant improvement in performance. The improvement of performance resulting from increased illumination is re-emphasized in Table 17. This table presents data showing the number of maneuvers in which major errors occurred for each light level. These major errors included touchdown of the aircraft or the development of a situation in which the safety pilot had to assume control of the aircraft.

TABLE 16

MEAN VALUES FOR THE FIVE MAJOR AXIS VARIABLES ACROSS NVG's ILLUMINATION LEVELS

| Standardized Discriminant Function Coefficient | Variable* | USAARL Light Factor Value 1.0 | 1.3 | 1.6 | 2.0 | 3.0 | 5.0 |
|---|---|---|---|---|---|---|---|
| .416 | Pitch-Standard Deviation | 1.843 | 1.660 | 1.716 | 1.492 | 1.439 | 1.569 |
| .134 | Roll-RMS Error | 1.453 | 1.372 | 1.429 | 1.293 | 1.287 | 1.181 |
| .572 | Heading-RMS Error | 4.714 | 5.090 | 5.356 | 5.011 | 4.090 | 3.978 |
| .509 | X Position-S.D. | 3.142 | 2.882 | 3.324 | 2.888 | 2.599 | 2.009 |
| .416 | Y Position-S.D. | 5.090 | 3.375 | 3.748 | 3.876 | 2.958 | 3.729 |

*Values for Pitch, Roll, and Heading are in degrees.
Values for X and Y Position are in meters.

TABLE 17

NUMBER OF MANEUVERS IN WHICH MAJOR ERRORS OCCURRED

| NVG's | | NES | |
|---|---|---|---|
| USAARL Factor Level | Number of Major Errors | USAARL Factor Level | Number of Major Errors |
| 1.0 | 3 | 4.0 | 6 |
| 1.3 | 4 | 5.0 | 9 |
| 1.6 | 3 | 6.0 | 7 |
| 2.0 | 4 | 8.0 | 4 |
| 3.0 | 0 | 10-13 | 5 |
| 5.0 | 2 | 10-18 | 3 |
| | 16 or 8.5% of total number of maneuvers | | 34 or 17.7% of total number of maneuvers |

## DISCUSSION

The present investigation has provided performance related information relative to the use of night vision goggles during low illumination levels. However, there are several practical aspects to be considered in arriving at conclusions from these data. First, there are several characteristics of the night vision goggles that impact total system performance. These aspects, as previously mentioned, are primarily related to the signal-to-noise ratio and gain characteristics of each individual set of goggles. Presently there is considerable variation in the measured signal-to-noise ratio for each intensifier tube. The set of goggles used in this study contained a closely matched pair of intensifier tubes and provided better resolution than had been previously observed in any other set of goggles used by USAARL.

The range of light gain for the goggles, varying from 7,500 to 15,000, and gain deterioration as tube life increases, also provides for wide variance in the performance between different sets of night vision goggles.

This investigation intentionally examined man-helicopter system performance at the low side of NVG's capability. Since the work was conducted at the extreme end of the NVG's performance curve and because of the considerable variability between sets of goggles, some caution must be used in generalizing these data to all sets of night vision goggles under all light conditions.

The second area which impacts the interpretation of this data concerns the type of measurement used. Due to an equipment malfunction, the only measures available for analysis were related to changes in the airframe. The sensitive measures of pilot control input were not available. However, since significant differences were obtained from the available measures, it would seem clear that the entire man-helicopter system is affected by changes in illumination during generally low light situations. Measures of this system performance indicate that there is not a successive increase in performance corresponding to all small increases in illumination. Significant improvement in system performance is evident when changing from a USAARL factor level of 1.0 to 1.3. Within the 1.3 to 2.0 level there are no significant changes in performance, but increasing the illumination from 2.0 USAARL factor establishes another significant improvement in performance. The lack of performance changes from the 3.0 to 5.0 USAARL factor levels indicates that sufficient illumination is available and that this increase in illumination did not markedly improve the man-helicopter system output.

Although further investigation may provide a more precise demonstration of exactly what level of illumination is required for optimal system performance, data obtained from this investigation indicate that use of the night vision goggles when the illumination level is below a USAARL factor of 2.0 will result in significant decreases in operational capability and mission effectiveness.

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